PUMPED LIQUID COOLING SYSTEM USING A PHASE CHANGE REFRIGERANT

Related Applications

This application is a continuation-in-part of copending application Serial No. 10/292,071, filed November 12, 2002.

Technical Field

The present invention relates to cooling of electrical and electronic components, and more particularly, to a liquid refrigerant pump to circulate refrigerant to multiple cold plate/evaporators in thermal contact with the electrical or electronic component to be cooled.

Background of the Invention

Electrical and electronic components (e.g. microprocessors, IGBT's, power semiconductors etc.) are most often cooled by air-cooled heat sinks with extended surfaces, directly attached to the surface to be cooled. A fan or blower moves air across the heat sink fins, removing the heat generated by the component. With increasing power densities, miniaturization of components, and shrinking of packaging, it is sometimes not possible to adequately cool electrical and electronic components with heat sinks and forced air flows. When this occurs, other methods must be employed to remove heat from the components.

One method for removing heat from components when direct air-cooling is not possible uses a single-phase fluid which is pumped to a cold plate. The cold plate typically has a serpentine tube

attached to a flat metal plate. The component to be cooled is thermally attached to the flat plate and a pumped single-phase fluid flowing through the tube removes the heat generated by the component.

There are many types of cold plate designs, some of which involve machined grooves instead of tubing to carry the fluid. However all cold plate designs operate similarly by using the sensible heating of the fluid to remove heat. The heated fluid then flows to a remotely located air-cooled coil where ambient air cools the fluid before it returns to the pump and begins the cycle again. This method of using the sensible heating of a fluid to remove heat from electrical and electronic components is limited by the thermal capacity of the single phase flowing fluid. For a given fluid to remove more heat, either its temperature must increase or more fluid must be pumped. This creates high temperatures and/or large flow rates to cool high power microelectronic devices. High temperatures may damage the electrical or electronic devices, while large flow rates require pumps with large motors which consume parasitic electrical power and limit the application of the cooling system. Large flow rates may also cause erosion of the metal in the cold plate due to high fluid velocities.

Another method for removing heat from components when air-cooling is not feasible uses heat pipes to transfer heat from the source to a location where it can be more easily dissipated. Heat pipes are sealed devices which use a condensable fluid to move heat from one location to another. Fluid transfer is accomplished by capillary pumping of the liquid phase using a wick structure. One end of the heat pipe (the

evaporator) is located where the heat is generated in the component, and the other end (the condenser) is located where the heat is to be dissipated; often the condenser end is in contact with extended surfaces such as fins to help remove heat to the ambient air. This method of removing heat is limited by the ability of the wick structure to transport fluid to the evaporator. At high thermal fluxes, a condition known as "dry out" occurs where the wick structure cannot transport enough fluid to the evaporator and the temperature of the device will increase, perhaps causing damage to the device. Heat pipes are also sensitive to orientation with respect to gravity. That is, an evaporator which is oriented in an upward direction has less capacity for removing heat than one which is oriented downward, where the fluid transport is aided by gravity in addition to the capillary action of the wick structure. Finally, heat pipes cannot transport heat over long distances to remote dissipaters due once again to capillary pumping limitations.

Yet another method which is employed when direct air-cooling is not practical uses the well-known vapor compression refrigeration cycle. In this case, the cold plate is the evaporator of the cycle. A compressor raises the temperature and pressure of the vapor, leaving the evaporator to a level such that an air-cooled condenser can be used to condense the vapor to its liquid state and be fed back to the cold plate for further evaporation and cooling. This method has the advantage of high isothermal heat transfer rates and the ability to move heat considerable distances. However, this method suffers from some major disadvantages which limit its

practical application in cooling electrical and electronic devices. First, there is the power consumption of the compressor. In high thermal load applications the electric power required by the compressor can be significant and exceed the available power for the application. Another problem concerns operation of the evaporator (cold plate) below ambient temperature. In this case, poorly insulated surfaces may be below the dew point of the ambient air, causing condensation of liquid water and creating the opportunity for short circuits and hazards to people. Vapor compression refrigeration cycles are designed so as not to return any liquid refrigerant to the compressor which may cause physical damage to the compressor and shorten its life by diluting its lubricating oil. In cooling electrical and electronic components, the thermal load can be highly variable, causing unevaporated refrigerant to exit the cold plate and enter the compressor. This can cause damage and shorten the life of the compressor. This is yet another disadvantage of vapor compression cooling of components.

It is seen then that there exists a continuing need for an improved method of removing heat from components when air-cooling is not feasible.

Summary of the Invention

This need is met by the pumped liquid cooling system of the present invention wherein cooling is provided to electrical and electronic components with very low parasitic power consumption and very high heat transfer rates away from the component surface. This invention also reduces the temperature drop required to move heat from the

component to the ambient sink.

In accordance with one aspect of the present invention, a liquid refrigerant pump circulates refrigerant to cold plate/evaporators which are in thermal contact with the electrical or electronic component to be cooled. The liquid refrigerant is then partially or completely evaporated by the heat generated by the component. The vapor is condensed by a conventional condenser coil, and the condensed liquid, along with any unevaporated liquid, is returned to the pump. The system of the present invention operates nearly isothermally in both evaporation and condensation.

Accordingly, it is an object of the present invention to provide cooling to electrical and electronic components. It is a further object of the present invention to provide such cooling to components with very low parasitic power consumption and very high heat transfer rates away from the component surface. It is yet another object of the present invention to reduce the temperature drop required to move heat from the component to the ambient sink.

Other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

Brief Description of the Drawings

Fig. 1A is a schematic block diagram illustrating a parallel configuration of the pumped liquid cooling system in accordance with the present invention;

Fig. 1B is a schematic block diagram illustrating a series configuration of the pumped liquid cooling system in accordance with the present invention; and

Fig. 2 illustrates a plurality of cold plate evaporator devices, each in thermal contact with a component to be cooled.

Detailed Description of the Preferred Embodiments

Referring now to Figs. 1A and 1B, there is illustrated a cooling system 10 which circulates a refrigerant as the working fluid. The refrigerant may be any suitable vaporizable refrigerant, such as R-134a. The cooling cycle can begin at liquid pump 12, shown as a Hermetic Liquid Pump. Pump 12 pumps the liquid phase refrigerant to a liquid manifold 14 , where it is distributed to one or a plurality of branches or lines 16. From the manifold 14, each branch or line 16 feeds liquid refrigerant to a cold plate 18. The condensing temperature of the refrigerant is preferably controlled so as to be above the ambient dew point where the cold plate evaporator device is located.

As illustrated in Fig. 2, each cold plate 18 is in thermal contact with an electrical or electronic component or components 20 to be cooled, causing the liquid refrigerant to evaporate at system pressure. None, some, or all of the liquid refrigerant may evaporate at cold plate 18, depending on how much heat is being generated by component 20. In most cases, some of the refrigerant will have evaporated and a two-phase mixture of liquid and vapor refrigerant will leave each cold plate 18, as shown by

arrow 22 in Figs. 1A and 1B.

In a preferred embodiment of the present invention, at this point in the operation of the system, each cold plate 18 discharges its mixture of two-phase refrigerant to conduit 24, as illustrated in Figs. 1A and 1B. For most applications, the conduit 24 is a tube. The conduit 24 is attached to condenser 28, comprised of a condensing coil 30 and a fan 32. Condenser coil 30, attached to conduit 24, condenses the vapor phase back to a liquid and removes the heat generated by the electronic components 20, shown in Fig. 2. Any unevaporated liquid in conduit 24 merely passes through condenser 28. In Figs. 1A and 1B, an ambient air-cooled condenser 28 is shown, using fan 32, although it will occur to those skilled in the art that any suitable form of heat rejection may be used without departing from the scope of the invention, such as an air cooled condenser, a water or liquid cooled condenser, or an evaporative condenser.

The condenser 28 operates at a pressure which corresponds to a temperature somewhat higher than the dew point temperature of the ambient air. In this way, it is impossible for water condensation to form, since no system temperature will be below the ambient dew point temperature. The condenser operating point sets the pressure of the entire system by means of the entering coolant temperature and its ability to remove heat from the condenser, thus fixing the condensing temperature and pressure. Also, since vaporized refrigerant is being condensed to a liquid phase, the condenser 28 sets up a flow of vaporized refrigerant from the conduit 24 into the condenser 28, without the need for any compressor to move the vapor

from the cold plate-evaporator 18 to the condenser 28. The liquid refrigerant exits the condenser 28, travels through conduit 34 as indicated by arrow 35, and moves to an additional volume 36, which holds a quantity of liquid refrigerant. Pump 12 pumps the liquid refrigerant from the additional volume 36 into the cold plate where the refrigerant evaporates, becoming a two-phase mixture, all without the need of any vapor/liquid separation. The two-phase mixture leaves the cold plate and goes into the condenser, which condenses the vapor into liquid, so that only liquid leaves the condenser.

The outlet of the additional volume 36 is connected to the inlet of the liquid refrigerant pump 12. At the pump 12, the pressure of the refrigerant is raised sufficiently to overcome the frictional losses in the system and the cooling cycle begins again. The pump 12 is selected so that its pressure rise is equal to or exceeds the frictional loss in the system at the design flow rate.

Unlike the pumped liquid single-phase system, the present invention operates isothermally, since it uses change of phase to remove heat rather than the sensible heat capacity of a liquid coolant. This allows for cooler temperatures at the evaporator and cooler components than a single-phase liquid system. Low liquid flow rates are achieved through the evaporation of the working fluid to remove heat, keeping the fluid velocities low and the pumping power very low for the heat removed. Parasitic electric power is reduced over both the pumped single-phase liquid system and the vapor compression refrigeration system. The cooling system of the present invention

comprises at least one component generating heat and required to be cooled, and at least one cold plate evaporator device in thermal contact with the at least one component. A vaporizable refrigerant is circulated by the liquid refrigerant pump to the at least one cold plate evaporator device, whereby the refrigerant is at least partially evaporated by the heat generated by the at least component(s), creating a vapor. A condenser condenses the partially evaporated refrigerant vapor, creating a single liquid phase. The vaporizable refrigerant from the pump is received by a first liquid conduit connected to the cold plate evaporator device(s). A second conduit from the cold plate evaporator devices), is connected to the condenser. A liquid return line is provided from the condenser to an inlet of the refrigerant pump.

An advantage over the heat pipe system is obtained with the system 10 of the present invention because the liquid flow rate does not depend on capillary action, as in a heat pipe, and can be set independently by setting the flow rate of the liquid pump. Dry out can thus be avoided. The cold plate/evaporator system of the present invention is insensitive to orientation with respect to gravity. Unlike heat pipe systems, the thermal capacity of the evaporator 18 of the present invention does not diminish in certain orientations.

Another advantage of the present invention over heat pipe and vapor compression based systems is the ability to separate the evaporator and condenser over greater distances. This allows more flexibility in packaging systems and design arrangements. The

present invention easily handles variation in thermal load of the components 20 to be cooled. Since any unevaporated liquid refrigerant is returned to the pump, multiple cold plates at varying loads are easily accommodated without fear of damaging a compressor. Since the current invention does not operate at any point in the system 10 at temperatures below ambient dew point temperature, there is no possibility of causing water vapor condensation and the formation of liquid water.

Having described the invention in detail and by reference to the preferred embodiment thereof, it will be apparent that other modifications and variations are possible without departing from the scope of the invention defined in the appended claims.